THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

Battelle
The Business of Innovation

TECHNOLOGY TYPE:	**ALTERNATIVE TECHNOLOGY FOR SEALED SOURCE RADIOGRAPHY CAMERAS**	
APPLICATION:	**PIPELINE INSPECTION**	
TECHNOLOGY NAME:	**IXS High Frequency Integrated X-Ray Generator**	
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ETV Joint Verification Statement

The U.S. Environmental Protection Agency (EPA) has established the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies. Information and ETV documents are available at www.epa.gov/etv.

ETV works in partnership with recognized standards and testing organizations, with stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field and laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Advanced Monitoring Systems (AMS) Center, one of six verification centers under ETV, is operated by Battelle in cooperation with EPA's National Risk Management Research Laboratory. The AMS Center evaluated the performance of an alternative technology for sealed source radiography cameras in gas and oil industry pipeline inspections. This verification statement provides a summary of the test results for VJ Technologies, Inc. IXS High Frequency Integrated X-Ray Generator.

VERIFICATION TEST DESCRIPTION

This verification test evaluated the ability of a technology with a non-radioactive source, VJ Technologies IXS High Frequency Integrated X-Ray Generator, to determine defects in pipeline similar to that found in an oil and gas industry refinery. Testing was designed in particular to identify defects through pipeline insulation. Test results were compared to results from a reference technology, the commonly used radiography camera with a Selenium-75 sealed source. Subsections of two pipes were examined by both the VJ Technologies IXS High Frequency Integrated X-Ray Generator and the radiography camera. Testing was conducted outdoors on June 1, 4, 5, and July 8, 2010 at Battelle's Pipeline Facility in West Jefferson, Ohio.

Pipe Sample 1 was a seam-welded carbon steel pipe approximately 35 feet in length and 8 inches in diameter. The wall thickness was 0.188 inches. To simulate the refinery environment, a portion of Pipe Sample 1 was insulated with calcium silicate material and jacketed with aluminum sheet metal. Four simulated corrosion defects (named P1-1, P1-7, P1-18, and P1-23), one natural corrosion defect (P1-9), and the weld next to the selected natural corrosion region were assessed on Pipe Sample 1. All areas of interest (defined as 'patches') were under the insulation placed on Pipe Sample 1, except for defect P1-1. Each patch on Pipe Sample 1 was a specific area of general corrosion with defined pits within it. Two images were taken 90 degrees to the centerline of the pipe for each patch. Pipe Sample 2 was a stainless steel alloy approximately 52 inches in length and 8 inches in diameter. The wall thickness was 0.515 inches. Three holes of varying diameter and depth were drilled into the pipe using handheld tools. A contact image and two images taken 90 degrees from the centerline of the pipe were collected for the defects on Pipe Sample 2. Physical measurements were collected for the drilled holes on Pipe Sample 2. The defects on Pipe Sample 1 were thoroughly characterized at the time of their creation, prior to the development of this verification test.

Both the radiography camera and the vendor collected analog images on General Electric (GE) phosphor imaging plates. After exposure, each imaging plate was placed into a Virtual Media Integration (VMI) 5100 computed radiography scanner where the image was retrieved using laser light scanning, and stored as a digital file.

The VJ Technologies IXS High Frequency Integrated X-Ray Generator was verified by evaluating the following parameters:

- ***Qualitative Detection of Defects*** – Qualitative results of defect detection were determined by viewing the image(s) of the defect, and assessing if the technology discovered a defect of appropriate size and shape in the appointed area. These results were then compared to those from the radiography camera.
- ***Percent Error –*** Quantitative results of defect detection were determined by performing percent error calculations on measurements from the images obtained by the radiography camera and the VJ Technologies device, then comparing these results to physical measurements of the defects.
- ***Percent Difference*** – Quantitative results of defect detection were determined by comparing the difference between measurements from the images obtained by the radiography camera and the VJ Technologies IXS High Frequency Integrated X-Ray Generator.
- ***Operational Factors*** – These included sustainability metrics such as maintenance needs, power needs, calibration frequency, data output, consumables used, ease of use, repair requirements, training and certification requirements, safety requirements, and image throughput.

QA oversight of verification testing was provided by Battelle and EPA. Battelle and EPA QA staff conducted technical systems audits of the testing, and Battelle QA staff conducted a data quality audit of at least 25% of the test data. This verification statement, the full report on which it is based, and the test/QA plan for this verification test are available at www.epa.gov/etv/centers/center1.html.

TECHNOLOGY DESCRIPTION

The following is a description of the VJ Technologies IXS High Frequency Integrated X-Ray Generator technology, based on information provided by the vendor. The information provided was not verified in this test.

The IXS technology is a compact, portable, x-ray generator. It integrates a high voltage (HV) power supply, an x-ray tube, and a filament supply into one single module. The product comes with a HV module connecting to a control module. The control module is powered by 110 volts (V) or 220 V of alternating current. The control interface uses a RS232 cable between the control module and a computer via a graphic user interface. The digital interface provides the ability to program and monitor the output voltage and current, monitor any fault conditions, and operate the interlock for the x-ray generator. The IXS series x-ray systems are designed to be used for a wide range of non-destructive testing applications including: industrial radiography, baggage security inspection, medical radiography and fluoroscopy, food and package inspection, and electronic component inspection. The product offers output power from 10 kilovolts (kV) to 160 kV, and up to 500 watts continuous output, with higher wattages available for pulsing applications. The IXS High Frequency Integrated X-Ray Generator is 16 inches long by 5.6 inches wide by 15 inches high. It weighs 59 pounds. The list price for a 500 watt (160 kV at 3.12 milliamp [mA]) model is $15,000. A computer, imaging plates, and image processing equipment are not included with the unit and must be purchased separately.

VERIFICATION RESULTS

Qualitative Detection of Defects. The VJ Technologies IXS High Frequency Integrated X-Ray Generator showed the patches with defects, natural corrosion, and the weld under the insulation, as well as the patch with defects on the uninsulated pipe. Raw images were comparable in quality to the radiography camera images for non-contact images. Both the radiography camera and the x-ray device had difficulties detecting the interior pipe wall on the images collected. This often led to an inability to make depth measurements on the defects for both the radiography camera and the x-ray technology. Detailed comparisons between images captured by the vendor and reference technology are provided in the verification report.

Percent Error and Percent Difference. Average percent differences were calculated for each defect characteristic (e.g., patch width and pit length) across all defects and ranged from 14% for all patch width measurements to 40% for all pit length measurements. Standard deviations were similar for patch width and length measurements.

Average percent errors for the radiography camera ranged from 13% for all patch width measurements to more than twice that with 28% and 30% errors for all pit length and width measurements, respectively. Standard deviations for the radiography camera average percent errors were similar across the different measurement categories such as patch width and pit length. The average percent error range for the results from the VJ Technologies IXS High Frequency Integrated X-Ray Generator was wider than the radiography camera, ranging from 2% to 38%. Pit dimension measurements from the VJ Technologies IXS High Frequency Integrated X-Ray Generator images were similar across all defects, and similar to the average percent errors for the radiography camera. This result indicates that measurements were derived from images from both technologies with similar accuracy. The average percent error for all patch dimensions based on images from the VJ Technologies IXS High Frequency Integrated X-Ray Generator was two to seven times lower than those for the radiography camera. The standard deviations for these average errors were also smaller for the VJ Technologies device, indicating that patch dimensions were more accurately determined using images from the VJ Technologies IXS High Frequency Integrated X-Ray Generator.

A variable sensitivity analysis of ASME Standard B31G, the method used to predict the remaining strength of corroded pipe, shows that this method is more sensitive to wall thickness than to the length or width of defects. The radiography camera was able to assess depth more often (four out of 12 pits) than the VJ Technologies IXS High Frequency Integrated X-Ray Generator (two out of 12 pits). When both were able to measure depth, the radiography camera was 50% more accurate. However, the interior pipe wall was not defined in images from either technology, so depth measurements were not able to be made to the internal pipe wall, but were instead based on the exterior wall. The ASME method is somewhat sensitive to errors in defect length estimations.

Length errors that are on the order of a wall thickness or two are typically tolerable. For all length measurements made, the radiography camera had one substantial measurement error, while the VJ Technologies IXS High Frequency Integrated X-Ray Generator did not have any. The radiography camera error occurred with the shallowest of the four patches tested. Quantification of the edges of shallow corrosion is often difficult, but these anomalies usually do not affect structural performance of the pipe. The defect width estimate is the least important parameter in corrosion characterization, and is often omitted by assessment methodologies.

Operational Factors. The VJ Technologies IXS High Frequency Integrated X-Ray Generator required the use of a typical 110 V or 220 V power outlet to operate the technology. A connection to a computer was also required to program the x-ray device for taking images, and to control the power output. The x-ray tube in the unit has a life-span of six to eight years.

The exposure time used for this test was one minute. To determine an appropriate exposure time and source power, initial images were taken and evaluated until the proper exposure situation was determined. This process took approximately one hour. Preparation of the VJ Technologies IXS High Frequency Integrated X-Ray Generator involved setting it up on a tripod stand, attaching the imaging plate and associated markers and image quality indicators to the pipe, and inputting the correct parameters into the software. This process took approximately 10-15 minutes for each image. Similar preparation times were noted for the radiography camera. Positioning the VJ Technologies IXS High Frequency Integrated X-Ray Generator for images above the pipe required the use of a platform to suspend the device. The x-ray device was placed 28 inches away from all patches and defects (except for the contact image collected), and was operated at 3 mA and 160 kV. The radiography camera was 32 inches away from the pipe, and used an exposure time of 1.5 minutes. These parameters were determined by the camera operator to provide optimal images.

Significant ghosting was noted on the imaging plates when using the x-ray technology. These burned images did not appear to impact the ability of the VJ Technologies IXS High Frequency Integrated X-Ray Generator to take new images or interfere with the interpretation of any images. The cost of each phosphor imaging plate was approximately $500.

The VJ Technologies IXS High Frequency Integrated X-Ray Generator produces x-ray radiation, though not from a radioactive source. Thus, a technician must be licensed to operate this equipment safely. No maintenance or calibration was needed for the VJ Technologies IXS High Frequency Integrated X-Ray Generator, although techniques can be applied (such as the use of comparators and other image quality indicators) to determine image quality and assist in image interpretation. There were no operational issues noted during the verification testing.

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